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Development of Multistage Converter for Outdoor Thermal Electric Cooling (TEC) Applications

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Abstract

The design of Transformer-less DC-DC converter for low voltage and high current thermoelectric cooling (TEC) applications is presented in this paper. The design of the converter was based on the combination of buck and boost converters topology. The prototype of the converter had been constructed and tested. The simulation results and measured data of the power circuit are analyzed and discussed. The maximum efficiency of the converter was about 80%, and it found to be suitable to be connected to the TEC load powered from solar panel power source.

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Keywords: SMPS, Transformerless Converter, DC Converter, MOSFETs, Cuk converter, Voltage Divider, TEC.

1. Introduction

The switching power supplies are based on the regulating elements, the switching power supplies consist of transistors that rapidly opened and closed the power switches. The resultant train of pulses is coupled to the output network which provides a smoothing of the DC output. [1]. The unregulated power supplies consist of a rectifier and filter which is not capable of providing a ripple free DC output voltage whose value remains reasonably constant.

The power conversion in consumer electronics devices uses characteristically high-efficiency switched mode power supplies (SMPS). Yet, reflecting the trend toward energy conservation there are increasing demands for power supplies with higher efficiency, lower loss and reduced stand-by waiting power [2][5]. Power processing has always been an essential feature of most electrical equipment. The differences in voltage and current requirements for different applications have led to the design of dedicated power converters to meet their specific requirements [1]. The most significant differences between the linear and the switch mode regulators involve their efficiency, size, weight, thermal requirements, response time, and noise characteristics.

A switching power supply could be used for powering the thermoelectric cooling module (TEC) prototype load. The thermoelectric modules (TEC) are solid-state heat pumps that operate on the Peltier effect. A thermoelectric module consists of an array of "p" and "n" type semiconductor elements heavily doped with electrical carriers. The array of elements is soldered so that it is electrically connected in series and thermally connected in parallel. This array is then affixed to two ceramic substrates, one on each side of the elements [7].

The TEC found in many applications, also TEC cooling modules are potential candidates for use in the thermal management of high temperature electronics applications for their widely commercially availability. The TEC modules have a maximum rated operating temperature of 200"C makes thermoelectric cooling an interesting option in the thermal management of high temperature electronic packaging [8,9].

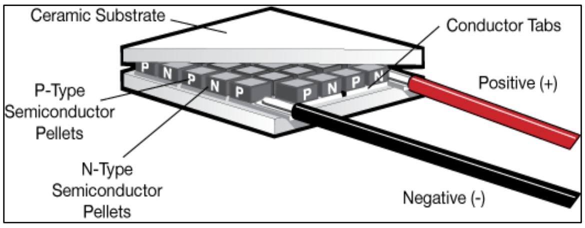

Figure1. Typical TEC Module.

2. Methodology

In switching supplies, the regulating elements consist of series connected transistors that act as rapidly opened and closed switches. The input AC is first converted to unregulated DC which will be chopped by the switching element operating at a rapid rate using high frequency

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PWM signal. The resultant pulse train is transformer-coupled to an output network which provides final rectification and smoothing of the dc output. Regulation is accomplished by control circuits that vary the on-off periods (duty cycle) of the switching elements if the output voltage attempts to chance.

Switching converters occupies between two type of converters which are the line regulated and the quiestiant resonant converters, the main problem of line regulator relates to the high power losses that is dissipated as a heat and also low overall efficient which is around 40%. On the other hand this type of regulators are cheep and simple compared to questiant resonant which are complex and costly but provide high efficient [5].

The elimination of magnetic elements and the use of switches and capacitors as a based design elements for the design of DC-DC converters, then light weight converter can be realized [2]. The idea of switch-capacitor (SC) is to charge capacitors is series, this will provide division of voltage and so wide range of step down achieved, then the charged capacitors have to be discharged in parallel in order to supply the stored energy to the load [4].

The Cuk converter basically derived from connecting a boost converter followed by a buck stage as shown in Figure 2. A practical realization of a Cuk converter could be as follows, the output polarity is inversed relative to input side [3].

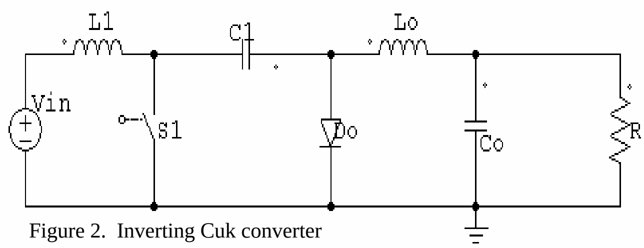

Figure 2. Inverting Cuk converter

The Cuk topology is an inverting topology in which the output polarity opposes the input one, for the purpose of obtaining same polarity referring to the input, a diode and a switch has to be added to a non-inverting Cuk converter. As shown in Figure3 the addition of D1 and S2 enable the transfer of energy stored in C1 with the same polarity from input relative to the output side. And then by combining the common element a single stage non-inverting Cuk stage is constructed [1].

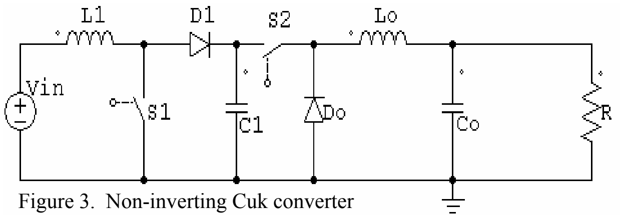

Figure 3. Non-inverting Cuk converter

By considering the topology of the non-inverting Cuk converter, then the new topology can be basically principled on dividing input voltage to charge series connected capacitor during switch on-time and the discharge the capacitor during switches off-time as shown in Figure4.

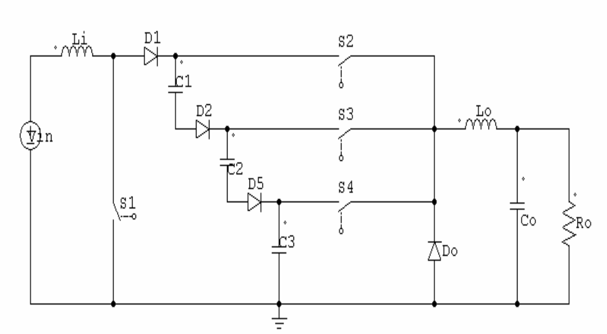

Fig 4. The 3-Stage non-inverting Cuk converter

The DC step down conversion associated with the use of transformer will lead to small value range of duty ration this will make it hard to switch ON and OFF the static switches. So the use of the proposed topology then large step-down voltage can be achieved without very small duty ratio and without usage of transformer. Therefore the losses related to usage of transformer can be eliminated [2,5].

The other advantage of this topology is that the energy transfer from input to the output is through the capacitors. These capacitors are charged on series during Off-time of the power switches and discharged on parallel during On-time of switches [6].

The use of high-voltage, fast switching power transistors, fast recovery diodes, and new filter capacitors with lower series resistance and inductance, could makes the switching supplies in a position of great concern in the power supply industry.

The heat pumping capacity of a TEC module is proportional to the current and is dependent on the element geometry, number of couples, and material properties [9,10]. By the use of thermoelectric modules it could effectively enhancing the thermal performance of air-cooled heat sinks [11].

The micro TEC (Thermo-Electric Cooler) can be used for hot spot cooling system of electric device in which it combined with heat sink. With the use of micro TEC lower maximum temperature at the hot spot can be obtained [12]. The performance of the TEC could be affected by the design of the cooling prototypes, it was found out that TEC combined with spreading devices could significantly extend air cooling performance [13]. The TECs with high cooling power capacities are nominal, a significant thermal enhancements could be achievable when currents and cooling configurations are optimized [14].

With the successful implementation of the multistage converter this cooling arrangement can be easily supplied from a PV panel with a DC-DC converter. The input power to the DC converter will be supplied from an input solar panel, the use of PV as a source of power for the converter, in which it could be a reliable solution for outdoor cooling applications where it is hard to find a source for powering the cooling components for the system.

3. Analysis

The non-inverting capacitance voltage divider current stress on static switches is quit reliable, whereas during the On-state of switch the boost originally switch handle the input current, and the other switches the current passes through S2,S3 and S4 is Io/3 per switching leg, which leads to reduction of the dissipated power.

With a similar way of analysis of single stage converter, the input/output voltage relation can be derived as given by:

$$V_o = \frac{DV_i}{3(1-D)} - \frac{D^2 V_{RS}}{3(1-D)} - DV_{RD} - DV_{RS} \quad (1)$$

By neglecting the voltage drop (V_{RS}, V_{RD}) then the output voltage is given by

$$V_o = \frac{DV_i}{3(1-D)} \quad (2)$$

And

$$D = \frac{3V_o}{V_i + 3V_o} \quad (3)$$

where D is the duty cycle.

4. Applications

Plate 1 shows a developed prototype for TEC cooling. This prototype uses 4 TECs of 15x15x3 mm size attached to the four sides. This prototype is tested using the converter and draw a current of 2 to 5 amps.

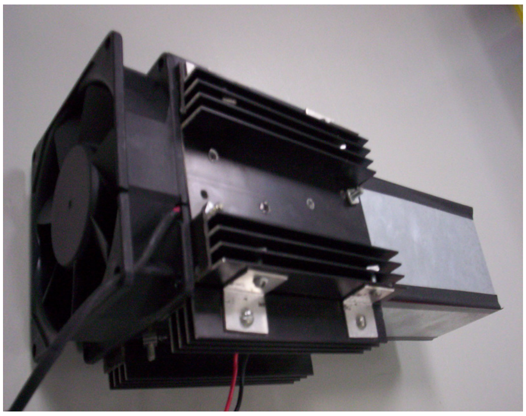

Plate 1: A pre-developed TEC cooling prototypes.

The Plate 2 shows the TEC modules attached to heat sink (30x17x4 cm), then the spaces have to be filled by polytetrafluoroethylene (PTFE) thin sheets, the cold side of TEC modules then being covered by an aluminum sheet as shown in Plate 2.

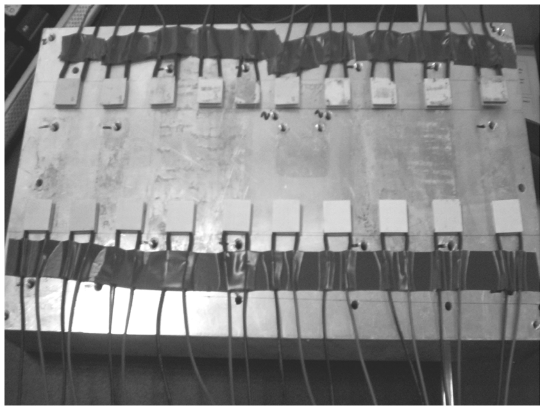

Plate 2: TEC modules attached to heat sink

The testing carton box been coated with a polytetrafluoroethylene (PTFE) sheets is used as a cabinet enclosure for testing the TEC functionality. The TEC was connected as a parallel of two series connected TEC's, these TEC's require a current of about 12A, which is provided by the converter.

5. Results

A. Simulation Software

The SIMCAD program is used for the evaluation of the proposed circuit. The PWM control driving signal for power MOSFETs can be generated by PWM IC control model using current or voltage mode voltage regulation. The useful of power measurement integrated feature allows easier observation for system dynamic performance. The power switched considered to be ideal thought out circuit simulation, so it will be operated as a traditional switch in ON and OFF states.

B. Measured and Simulated Results

Figure 5 shows the simulation of input and output current waveforms, the upper is the converter output current and the lower is the input current.

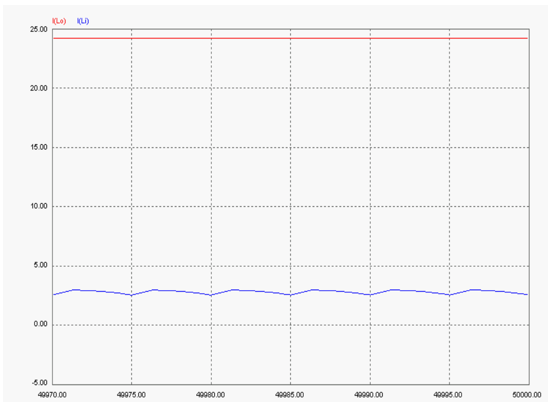

Figure 5. The input and output current waveforms

Figure 6 show the measured waveform of the voltage across the power switch S1 was matched with the waveform obtained from simulation that is illustrated in Figure 7. Also Figure 7 shows the simulated current

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through the switch S1, the maximum current being about 3.5A

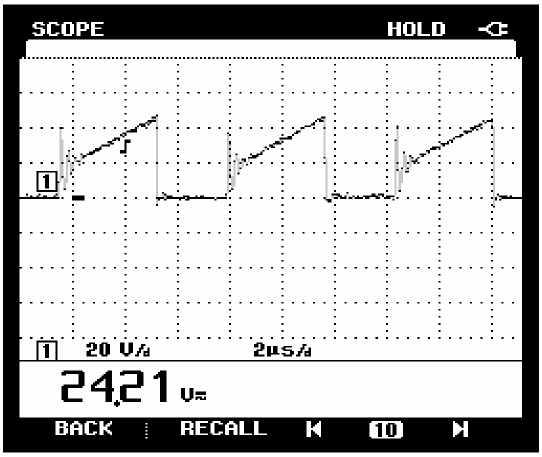

Figure 6 Measured voltage across MOSFET S1

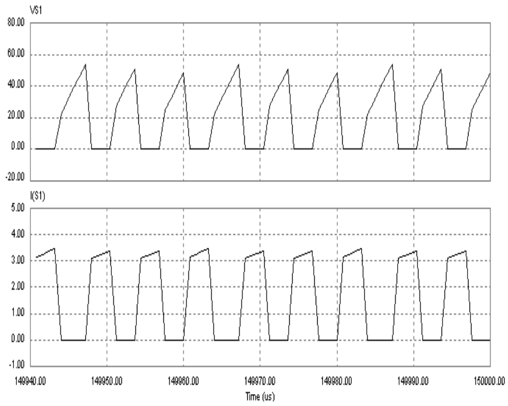

Figure 7 Simulation waveforms of MOSFET switch S1

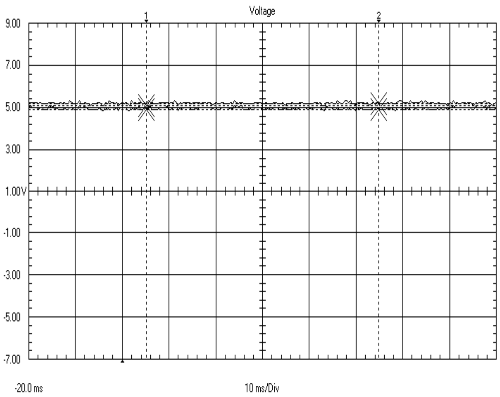

Figure 8. Measured output voltage V_o with Fluke power quality analyzer

Figure 8 shows the measured output voltage analyzed buy Fluke power quality analyzer software. The simulation results of output current and voltage are shown in Figure 9, the upper waveform shows the output current, and the lower one shows the output voltage.

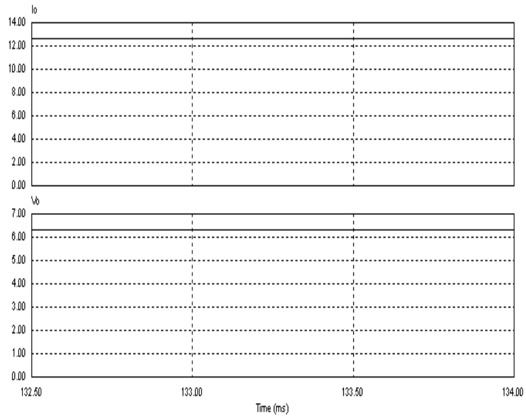

Figure 9. Simulated output voltage and current

Figure 10 shows the converter efficiency versus output power. The figure shows the efficiency at power ranges up to 70W. The figure also shows the converter ability to supply the rated load with efficiency up to 80%. As illustrated in the figure the converter efficiency varies with load change from 35% up to 80% at full load.

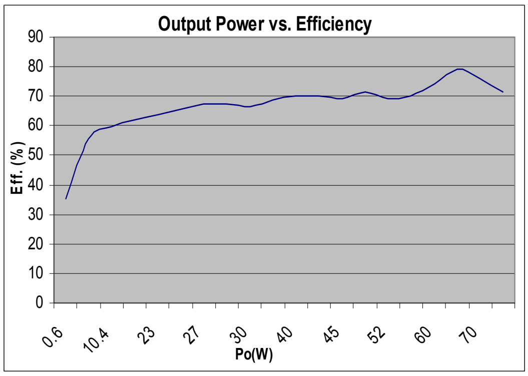

Figure 10 Output power versus efficiency

Plate 3 shows the practical implementation of the power circuit PCB board of the converter, and Plate 4.4 shows the power circuit PCB board.

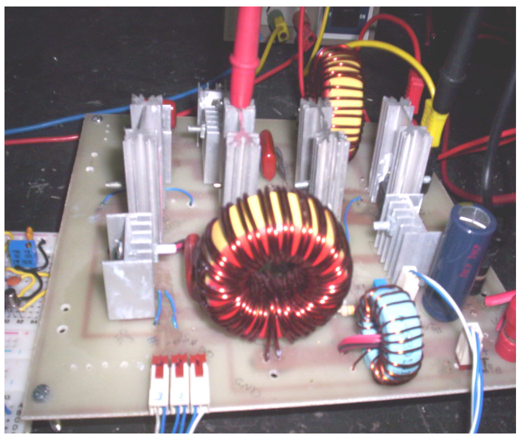

Plate 3. Power circuit PCB board

6. Conclusion

The design of transformer-less converter for low voltage and high current is presented in this paper. The topology was used for device cooling system. For application up to 70 W the topology had show a maximum efficiency of 80%. The implemented converter found to be suitable to supply TEC load connected to PV power source for outdoor application.

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